The Lab of the Future

Lab of the Future. The phrase call to mind a place where scientists, engineers or, frankly, researchers of any discipline, can step around the miserable aspects associated with having a lab (planning, maintenance, scheduling, and preparation) and get straight to the process of experimentation. Imagine a place with floating displays, information at the tip of a finger and no barriers to analysis, synthesis or creativity. We see something like the basement workspace of Tony Stark, the businessman alter-ego of Stan Lee's superhero Iron Man in the comics and the movies. It is all about "bring this vision closer" through modern information technology. But the question remains: Where do we find this ideal basement?

Well, in the "real world" we still have to build it. So, let's start with a list of what we'll need, beginning with the basics: data, a data management systems, and knowledgeable research teams. These need to be established in such a way that researchers can collaborate from anywhere, introducing the notion of the lab of the future being a "global" network of labs. It also introduces the need for networking technology, a foundation to build from.

Visualizing a blueprint for the final structure, I suggest our project will entail six technology ~~layers~~areas, call them Lab of the Future Technologies~~y~~ (LOFT) 1 through 6; with LOFT-~~-~~1 broadly comprised of networking technology, the array of hardware and software necessary to craft a global network. Some LOFT-1 technology is commercially available, and some still exists on a wish list. We will find that some mix of available and emerging technology will exist in all six lofts, with the balance shifting to emerging technology as we move upward.

When we speak of moving upwar~~e~~d, it is not to su~~b~~ggest that each ~~l~~loft is a ~~physuca~~physical~~k~~ layer of technology that much be achieved before moving to the next ~~loft~~LOFT. Work is done across~~ is done across~~ the blueprint simultaneously, with each LOFT taking us to a higher level of technological capability.

Let's look at LOFT-2, where we have automatic retrieval of data and displays via personal assistant technology. Imagine our LOFT-1 network equipped with a programmer, logistics manager, planner, assistant—in essence a robotic information technology manager.

Much of ~~-~~the technology required at LOFT-2 has already caught on in consumer electronics. The man on the street is getting directions, just as the man on the couch is ordering pizza, over personal computers and cell phones using applications such as Google Assistant, Alexa, Microsoft's Cortana, Apple's Siri, and Samsung' Bixby.

~~Higher-level~~ More capable versions of this (change I made) technology can also be accessed. NASA's Ground Systems Development Operations Program, for example, is currently evaluating Assistant for Understanding Data through Reasoning, Extraction and sYnthesis (AUDREY), an ~~IT~~ assistant developed by Jet Propulsion Laboratory with funding from the U.S. Department of Homeland Security, as well as NASA's own Kennedy Automated Test Engineer (KATE). Both are intended to help the Launch Control Team, initially as data agents with the goal of becoming ~~artificially~~ intelligent ~~research~~ partners.

Studies are also under way in the Kennedy IT Advanced Concepts Lab (ITACL) into the viability of Internet of Things (IoT) technologies with the goal of IoT elements being supervised by Intelligent agents. It is hoped that one day an IoT-enabled autonomous system will have the ability to manage equipment and ultimately participate as an automated member of the team member, not entirely unlike the HAL 9000 computer in Arthur C. Clarke's *2001: A Space Odyssey* (though we aren't ready to turn over control of certain airlocks).

The role of the human information technology manager and data analyst is significantly elevated at LOFT-2. Here, let me introduce the Kennedy Space Center's Launch Team, which operates within the Ground Systems Development Operations Program, as an analog for the lab environment we are constructing here. The team's laboratory architects and engineers have worked over time to integrate a

range of tools, data models, and disciplines, including flight simulators, process protocols, planetary physics, audio/video data, atmospheric physics, and planning systems to provide shared visualization of multi-decade projects such as the Mars landing. The work has required a look forward to the needs of future researchers with knowledge of historic experimental results and decisions of impact to a global, if not inter-global, network of labs *in* the future.

The next need is for display technology able to represent this new information and knowledge. Putting *Iron Man* comics aside for the time being, we turn to a broader entertainment sphere, the multi-billion dollar digital game industry, for inspiration as we conceptualize LOFT-3. Here we encounter virtual- and augmented reality systems, pivoting to a practical question that has been waiting in the wings: What does our visualization system need to display?

For an answer, we advance to the first of our data technology LOFTs, LOFT-4, where again we find there are existing technologies that can be applied to locating archived information—reports, graphs, tables, or images catalogued in legacy data systems—and communicating them across our network. Large data sets are entering research, but so are Big Data management tools that can handle them at LOFT-4. At

LOFT-5, however, we encounter a higher level of data, comprised of emerging and undiscovered data—the unknown unknowns of the research domain. The relevance of these data, existing in media ranging from the unfamiliar to the currently inconceivable, may only come to light in the future when studied in contexts that are also in an emergent state. And they can only be handled with the introduction of machine learning techniques—algorithms that significantly enhance the data network with the ability to “learn from experience” about the likely ~~the~~ trajectory of new data entering the system and to craft a pathway for the unknowns into the evolving managed database of the known.

We have taken a giant step into the realm of the unsolved at LOFT-5, where there are no available drop-in tools.

As we develop visualization at the frontier, our focus will be on developing data representation techniques suitable for both humans and ~~artificially~~ intelligent machines, conscious of the fact that the machines operate at an astronomically higher capacity than the humans in most regards. A 40,000-line table of results is manageable for a computer and floats through the cloud with no problem. But it will overwhelm~~s~~ the human researcher.

In search of such techniques, Kennedy Space Center worked with temporal spatial and meta-data formats to develop Distributed Observer Network (DON) and the Model Process Control (MPC) language, both of which the Center is interested in sharing with researchers outside of NASA. The hard work is to understand and develop structures that can be rapidly understood by both the human and machine teams without obscuring subtle elements of future interest. Technologies supporting a rich human-to-machine engagement (LOFT-6) will pay great dividends, but are also far away from the “solved” side of the page.

The Lab of the Future interface will certainly resemble Stark’s artificial intelligence platform, Just a Rather Very Intelligent System (JARVIS), the enabler *Iron Man* introduced to the world, an environment of amazing efficiency and effectiveness in research. One in which the researcher is freed from all the old fashioned “lab stuff~~.~~” that JARVIS is doing that behind the scene.

NASA is pushing forward, but LOFT1- through 6 also need~~s~~ to be developed in the broader world in order to provide automated assistance across the~~ entire~~ research universe in chemistry-intensive fields such as materials science and drug discovery. Developments need to be shared across all disciplines. NASA is~~now~~ interested in sharing its experiences at the new frontier of the laboratory, and hopes build on its heritage of passing technologies into the world at large in labs of the future.

But, without a vision of the ultimate Lab of the Future, one that extends several steps beyond the science and technology that can easily be deployed today, new developments are as likely to burden the researcher as they are to free the researcher. In Stark’s world, success comes not from a random

assemblage of cool tools, lasers, and robots, but from their integration with ~~of in~~ JARVIS, the intelligent system ~~that~~ enabling~~es~~ ~~Iron~~ Tony~~Man~~ to achieve his astronomical breakthroughs.